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**Jeon et al.**

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(54) **SEMICONDUCTOR DEVICE**

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This patent is subject to a terminal disclaimer.

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**H01L 31/072** (2012.01)  
**H01L 31/109** (2006.01)

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USPC ..... **257/192**; 257/194; 257/195

(58) **Field of Classification Search**  
USPC ..... 257/76, 77, 192, 194, 195, E21.403,  
257/E29.068, E29.246  
See application file for complete search history.

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*Primary Examiner* — Hung Vu

(57) **ABSTRACT**

Provided is a nitride semiconductor device including: a nitride semiconductor layer over a substrate wherein the nitride semiconductor has a two-dimensional electron gas (2DEG) channel inside; a drain electrode in ohmic contact with the nitride semiconductor layer; a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode; a dielectric layer formed on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and a gate electrode disposed on the dielectric layer to be spaced apart from the drain electrode, wherein a portion of the gate electrode is formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween, and a manufacturing method thereof.

**13 Claims, 6 Drawing Sheets**

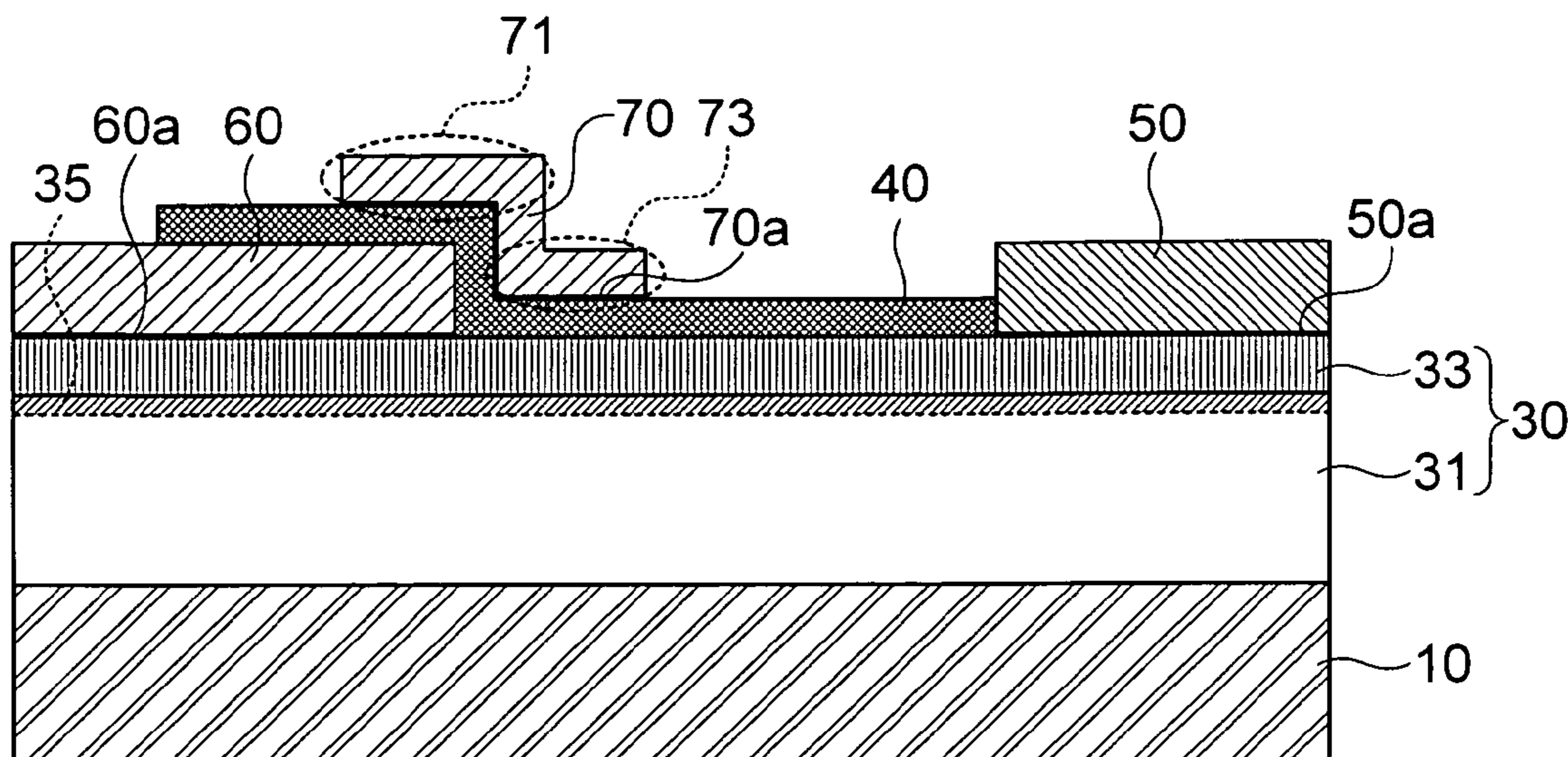


FIG. 1

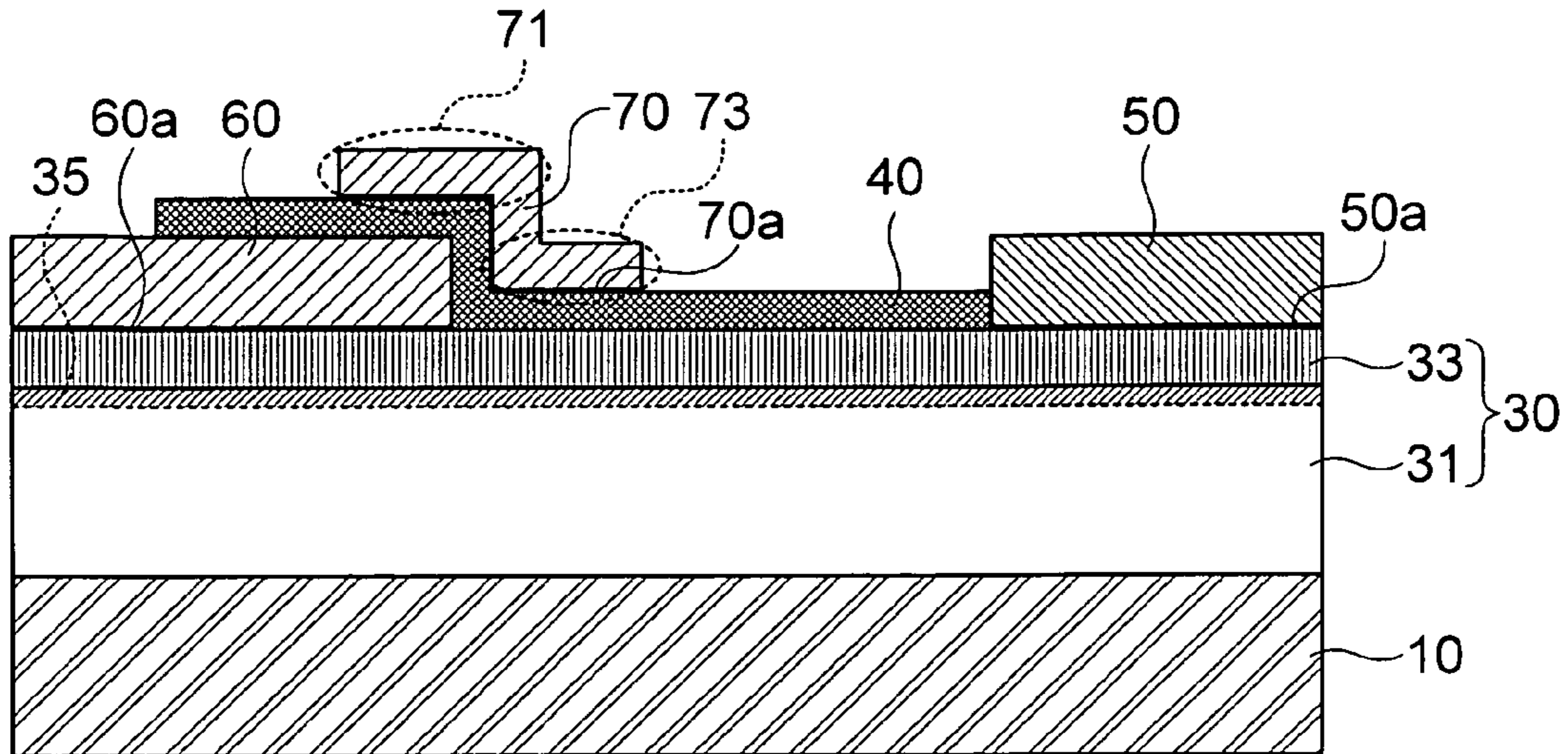


FIG. 2A

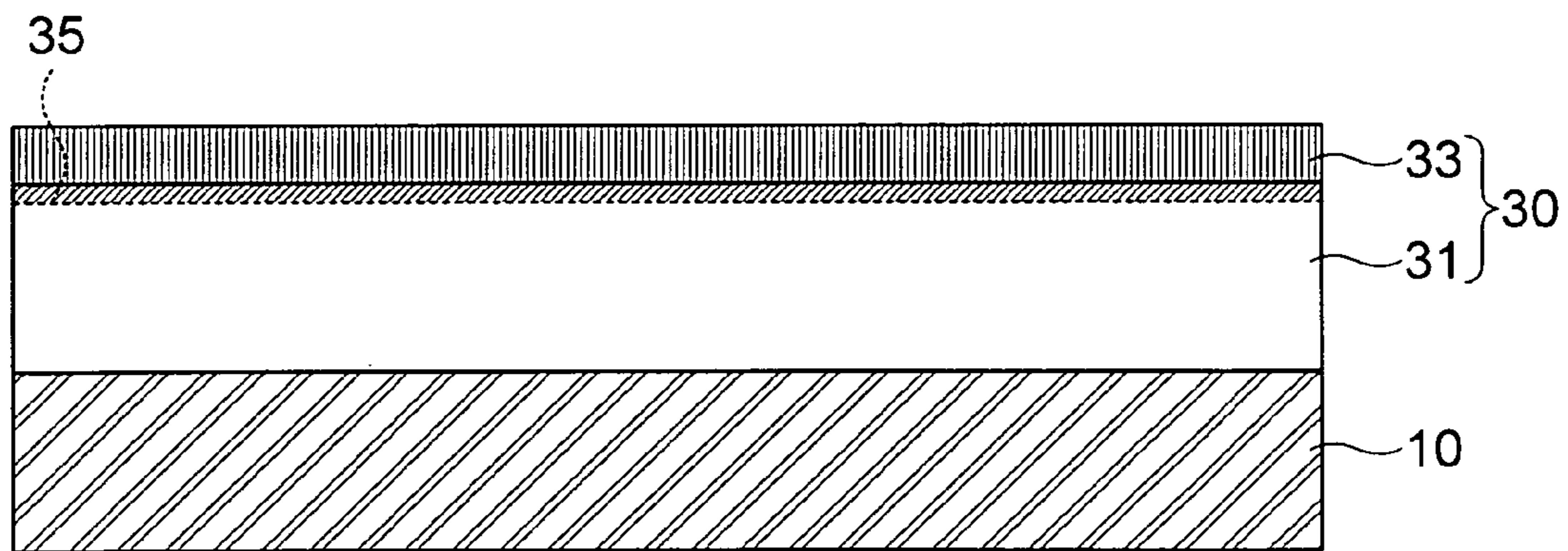


FIG. 2B

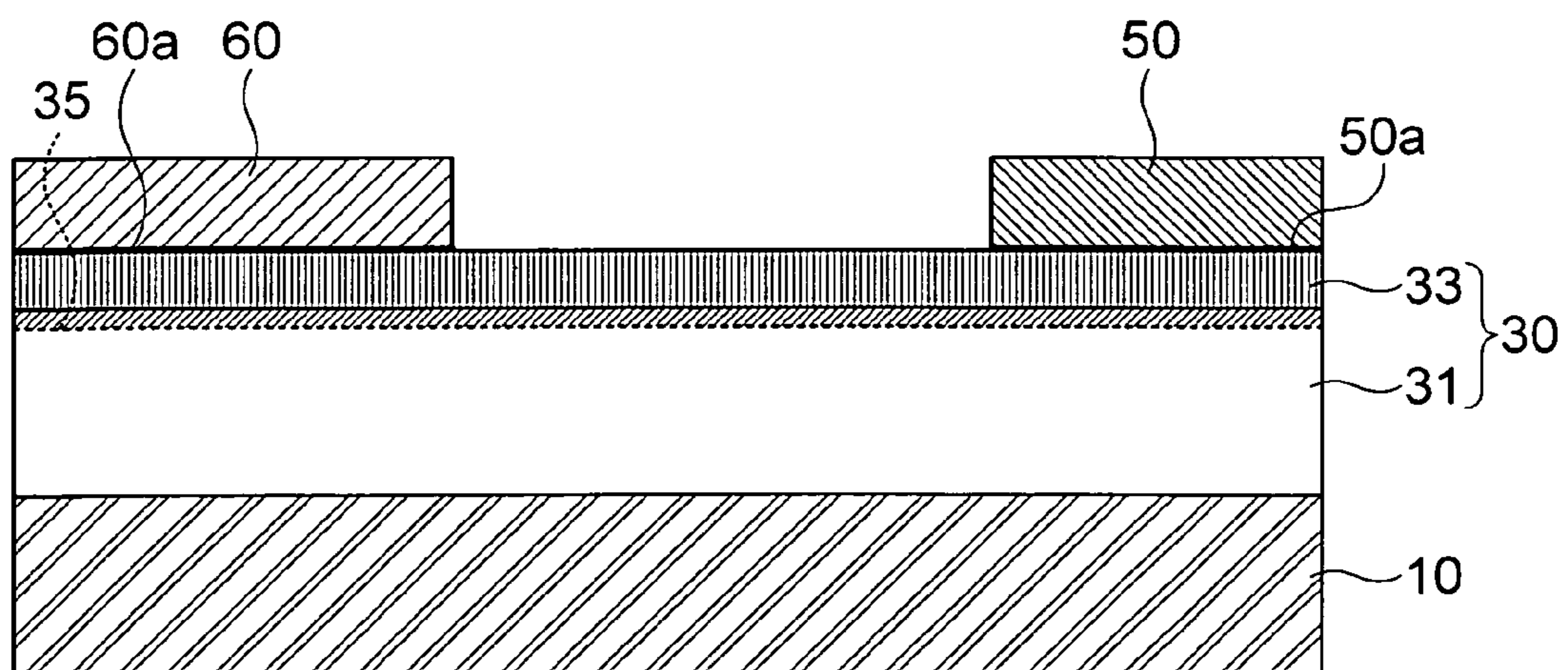


FIG. 2C

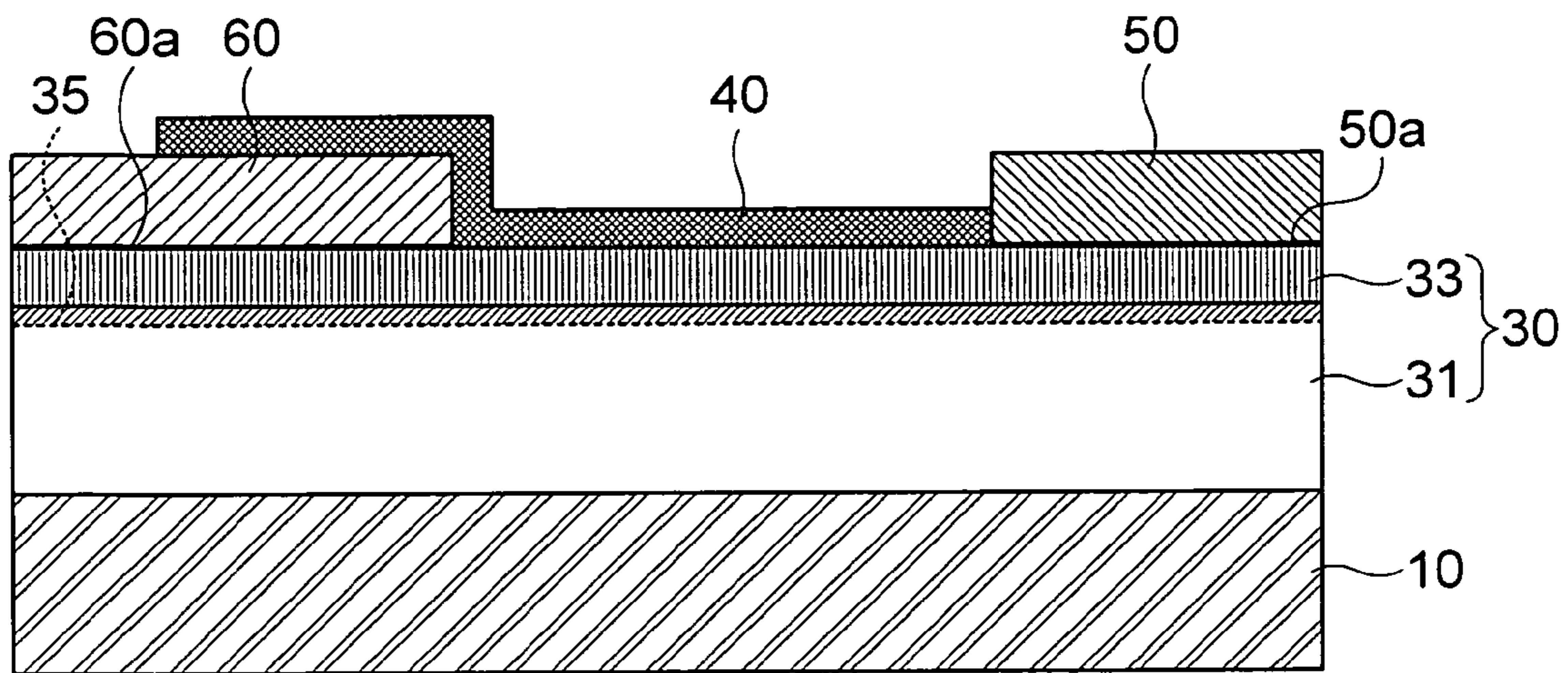


FIG. 2D

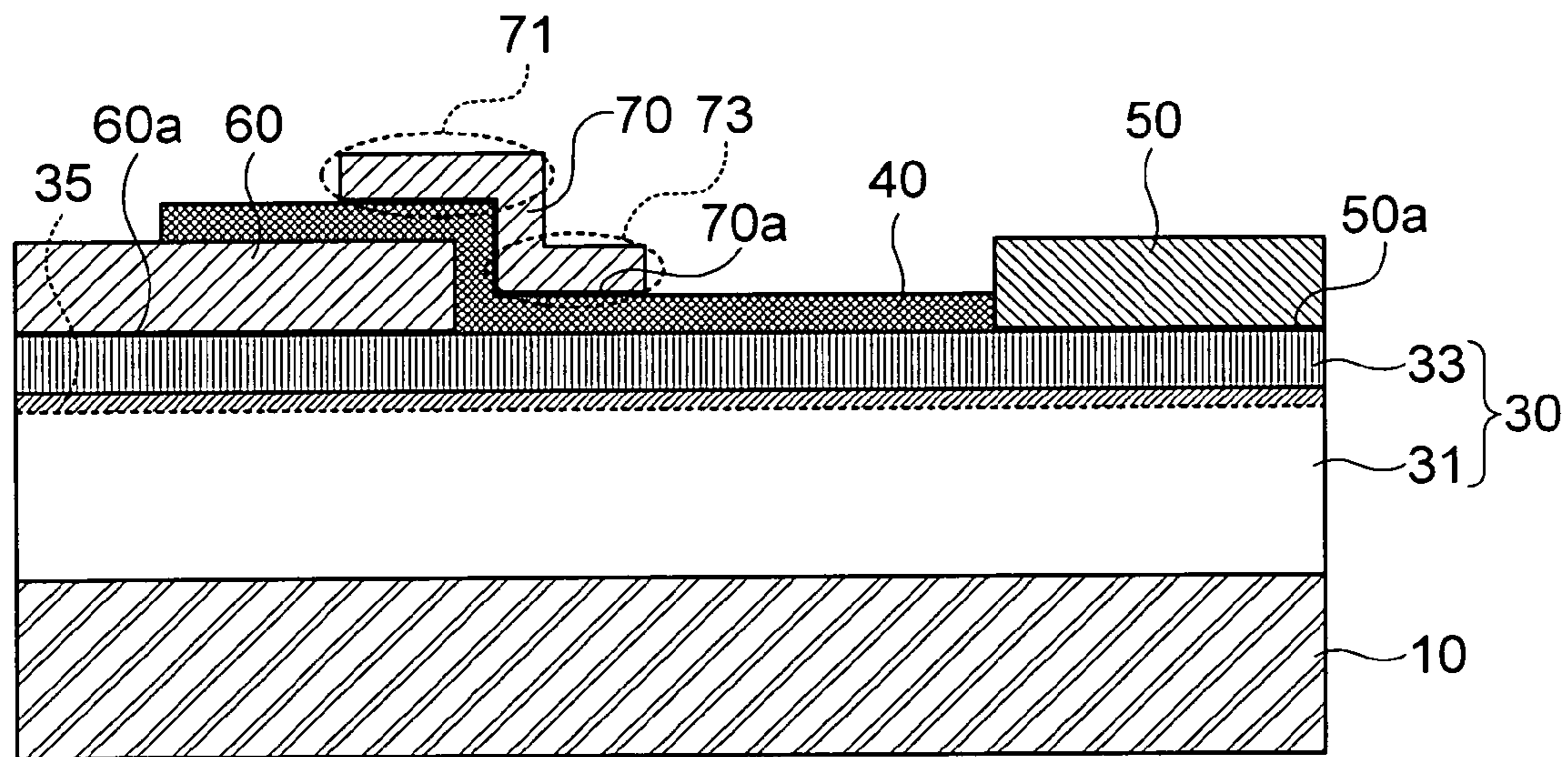


FIG. 3

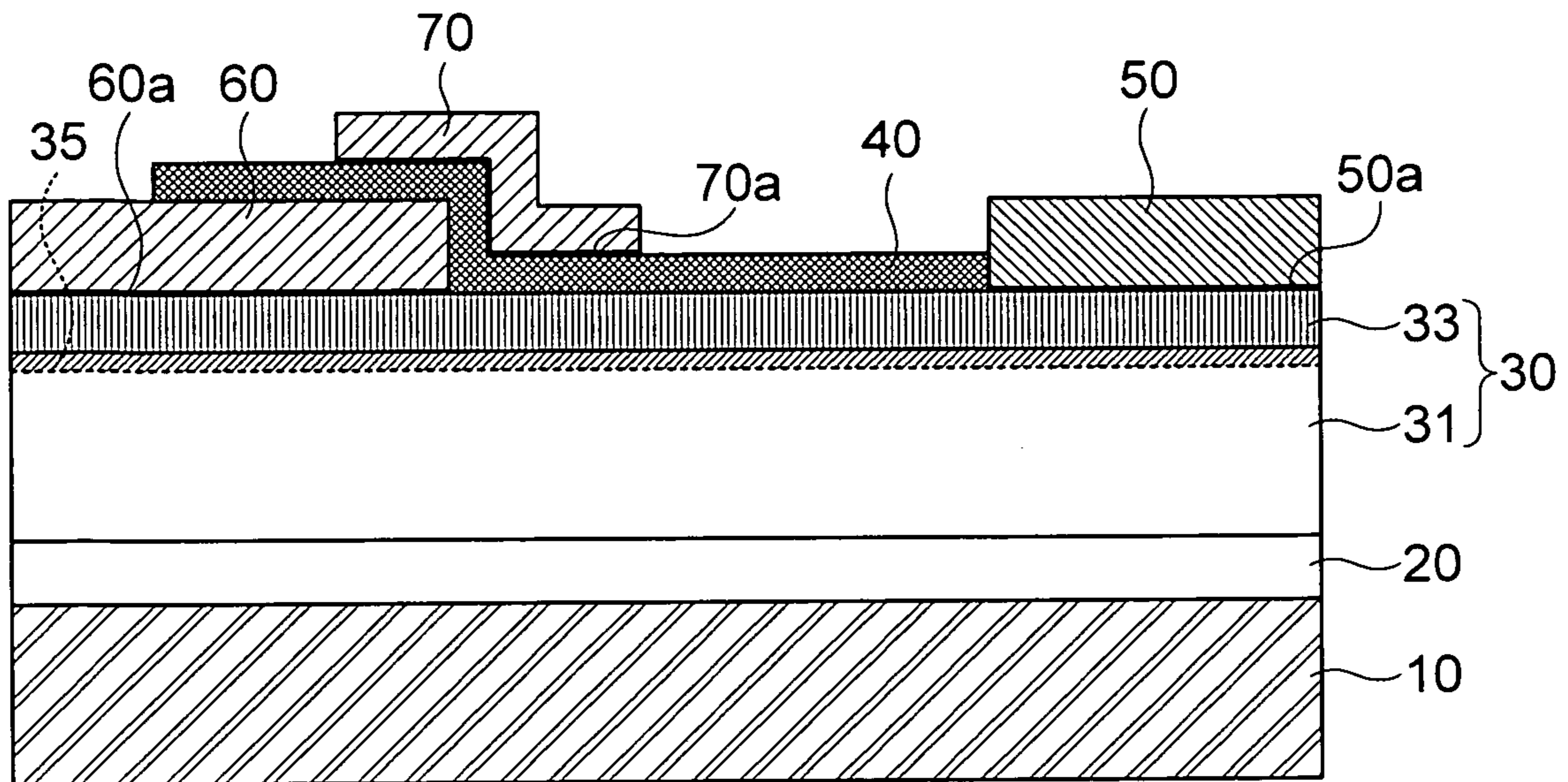


FIG. 4

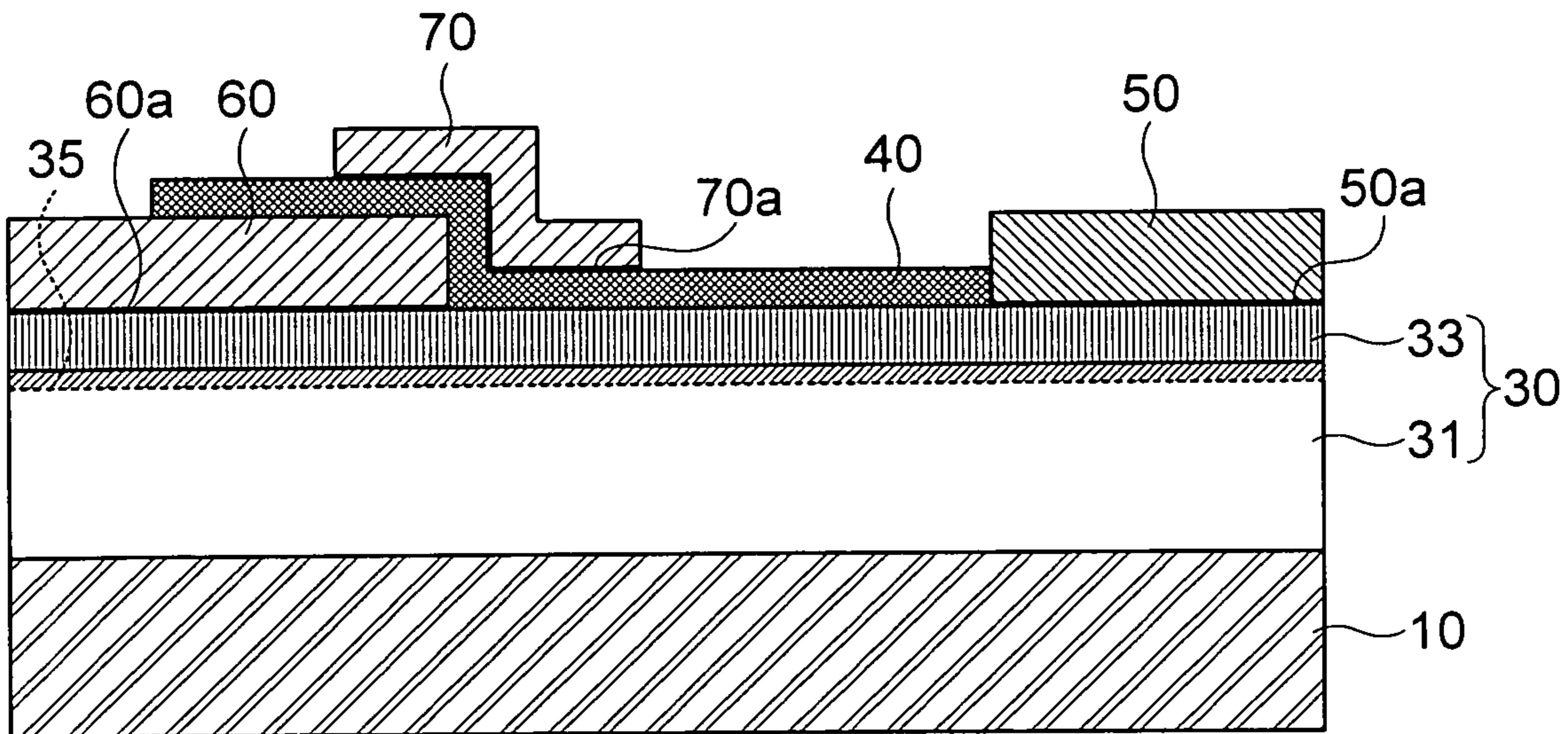


FIG. 5

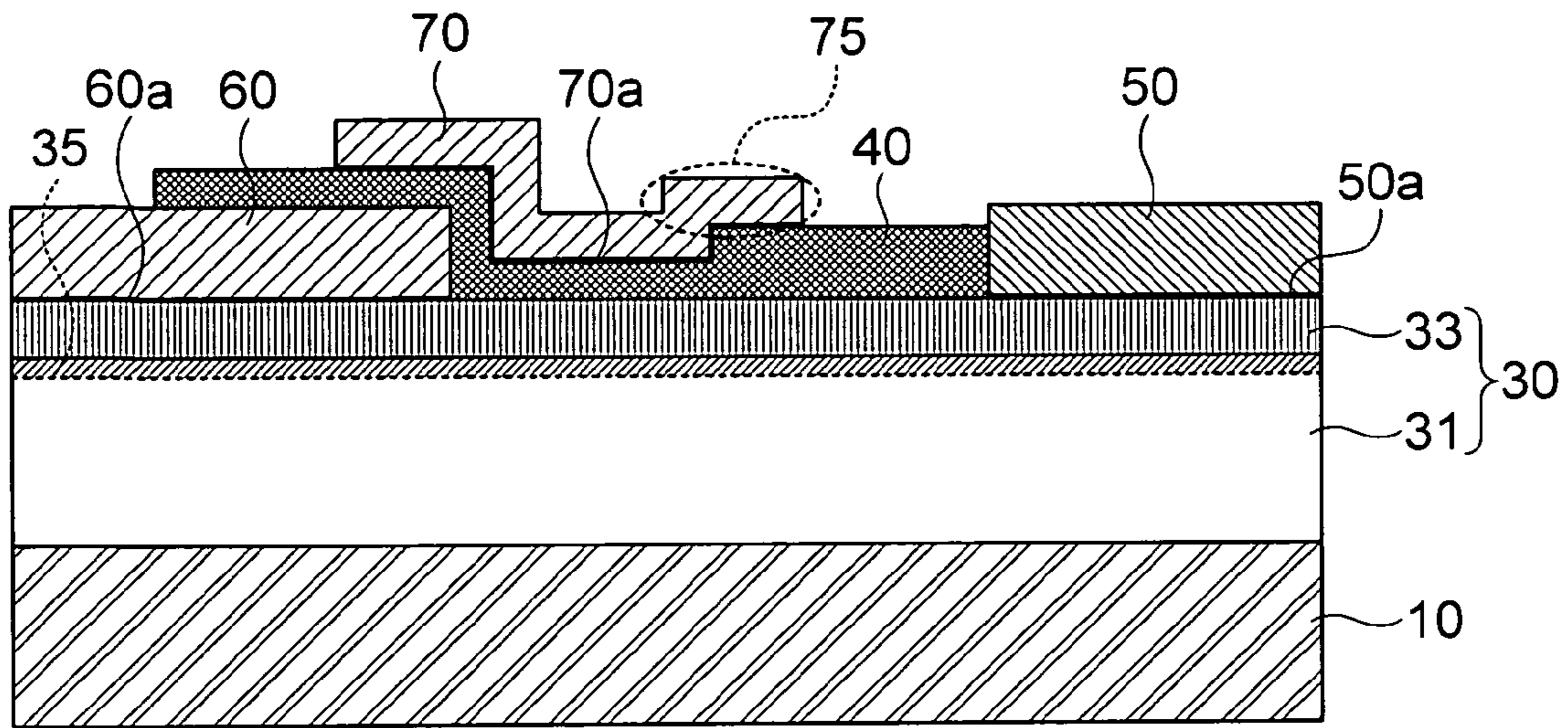


FIG. 6A

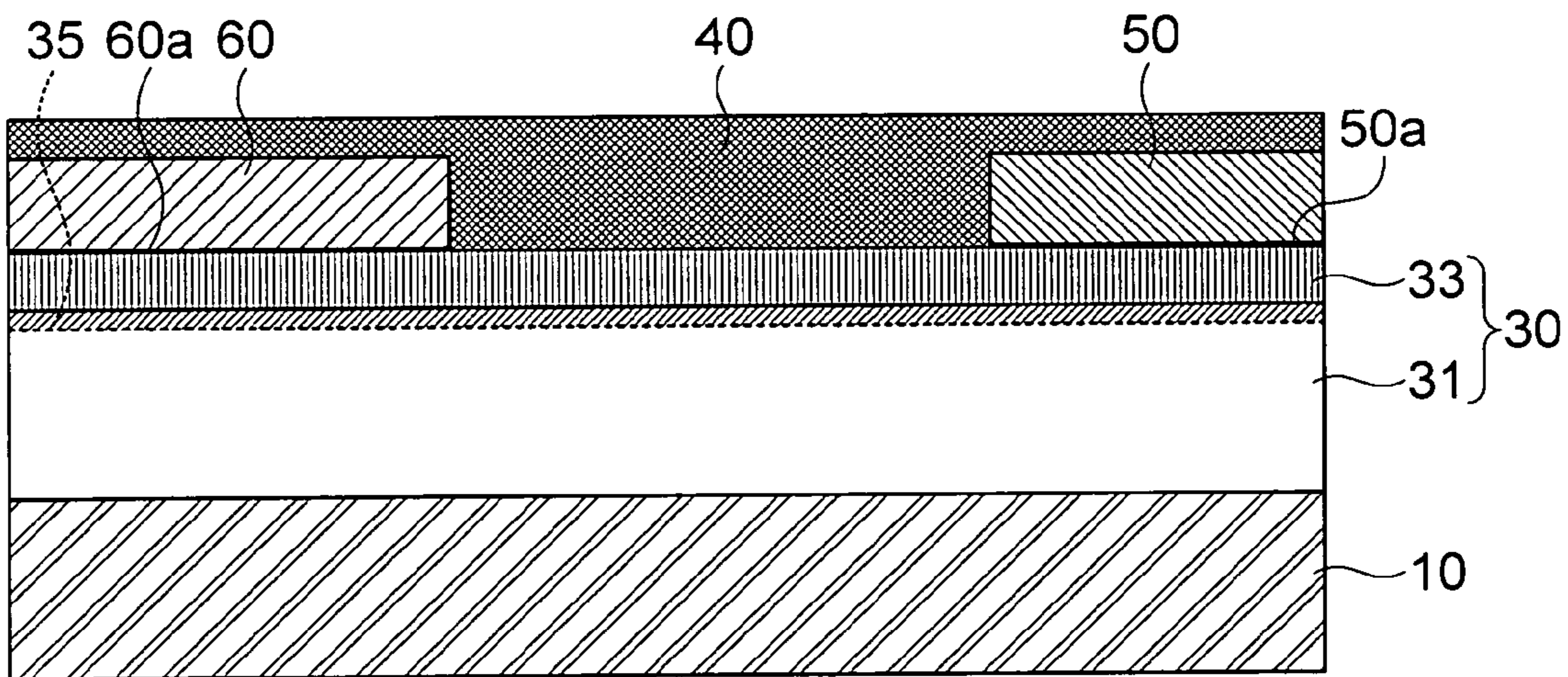


FIG. 6B

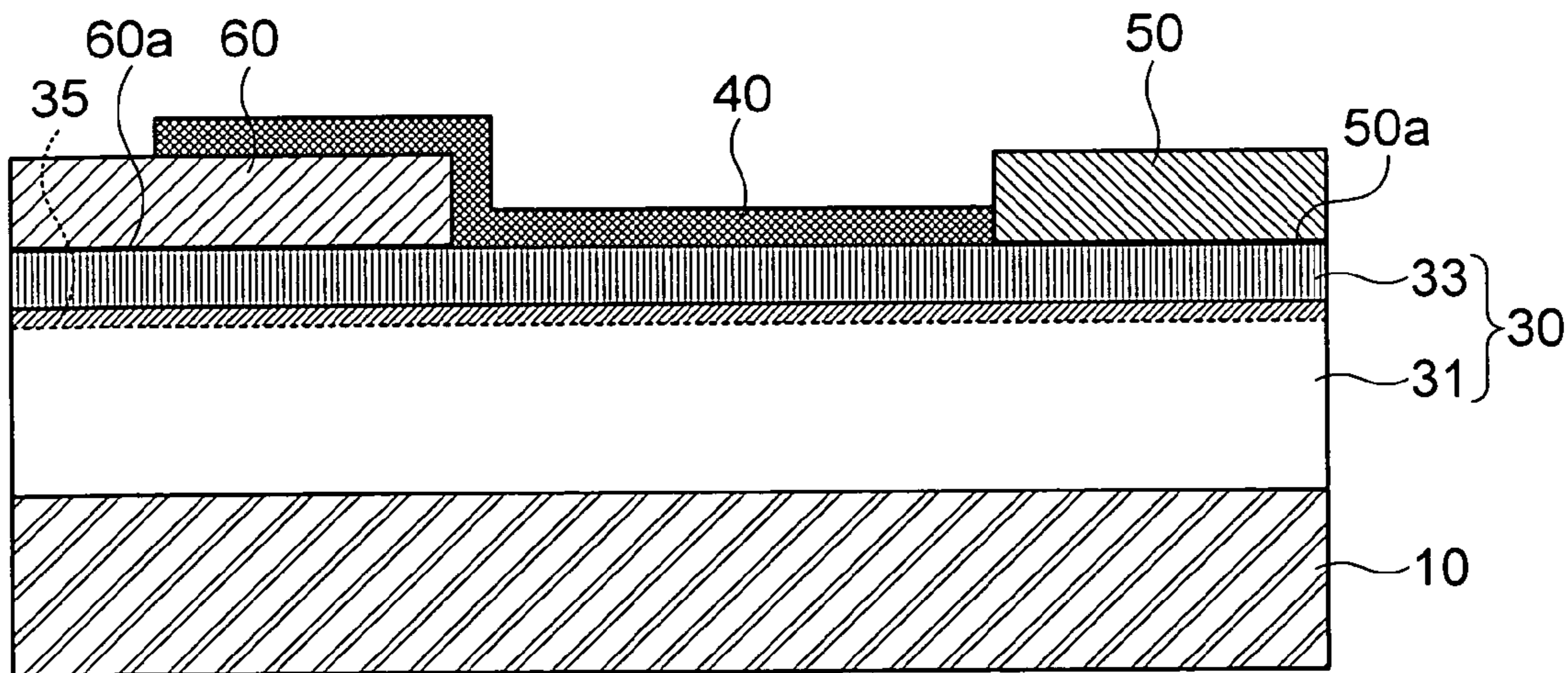


FIG. 6C

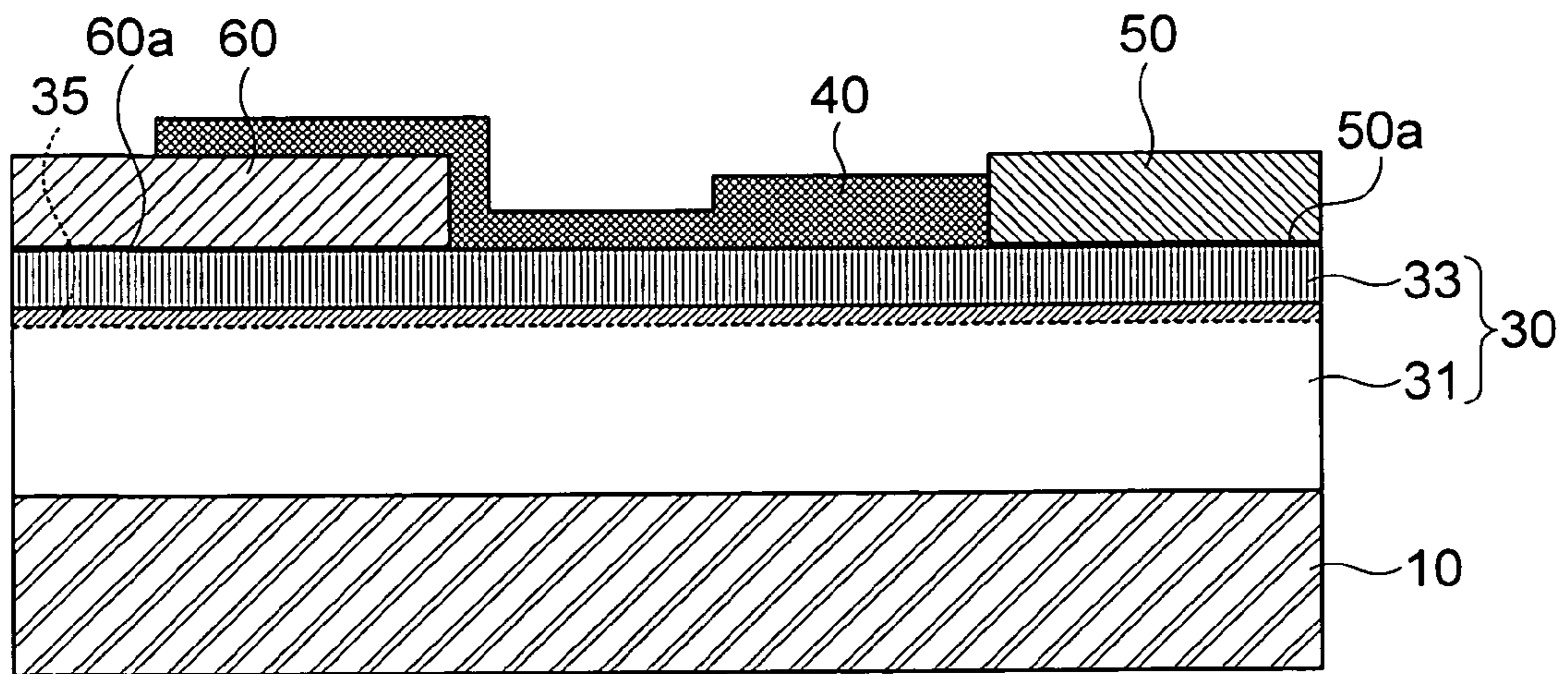


FIG. 6D

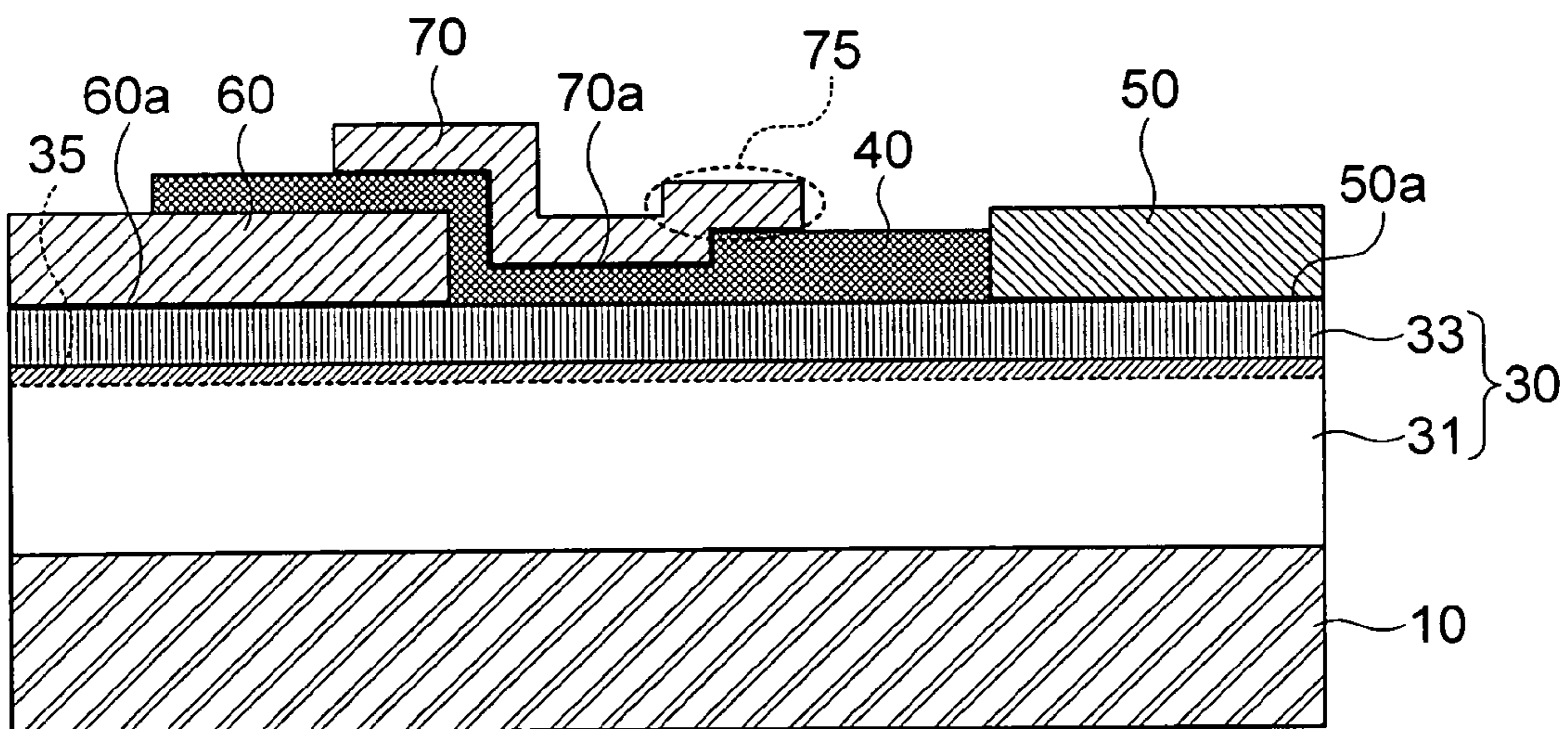


FIG. 7

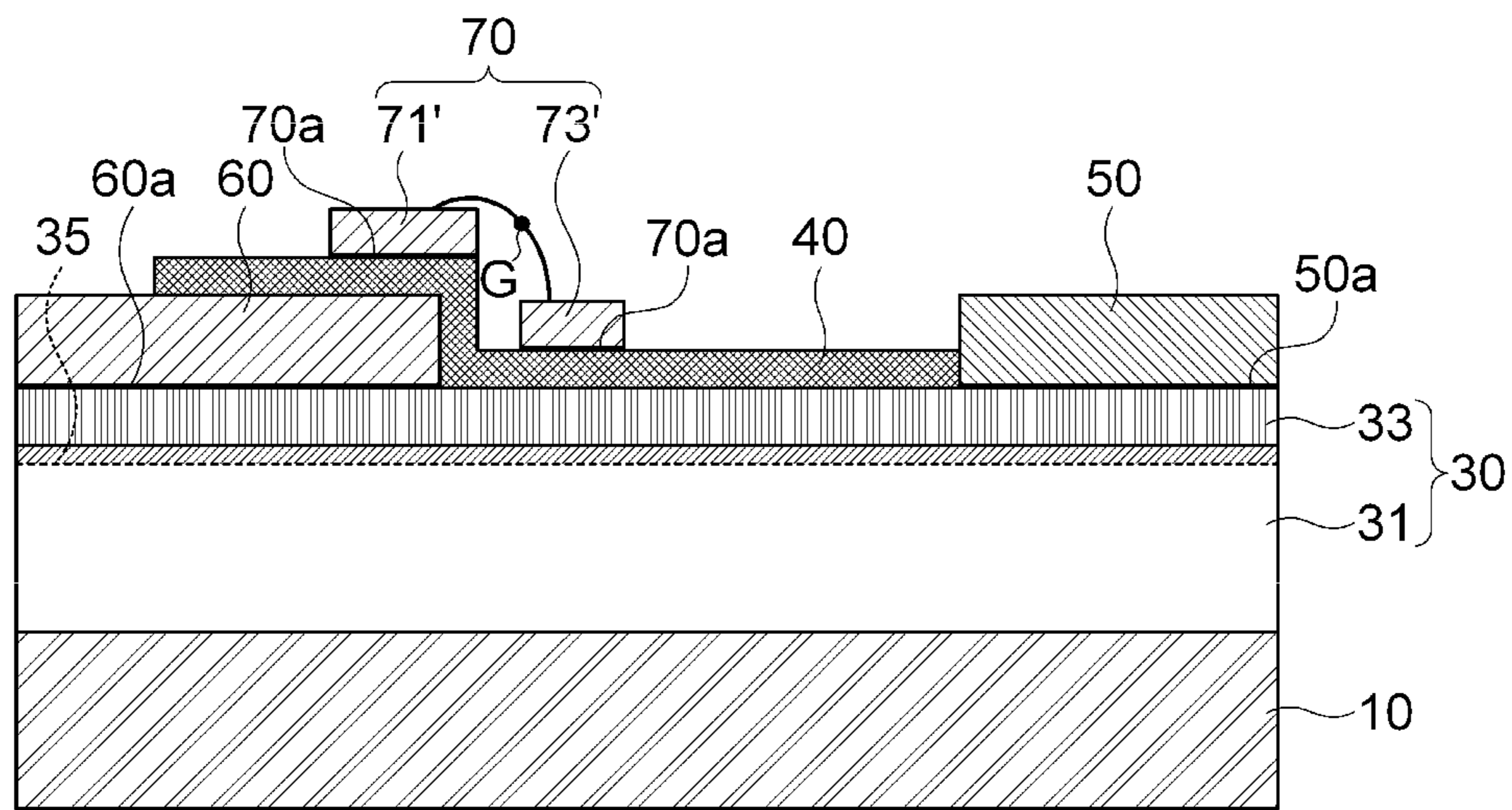
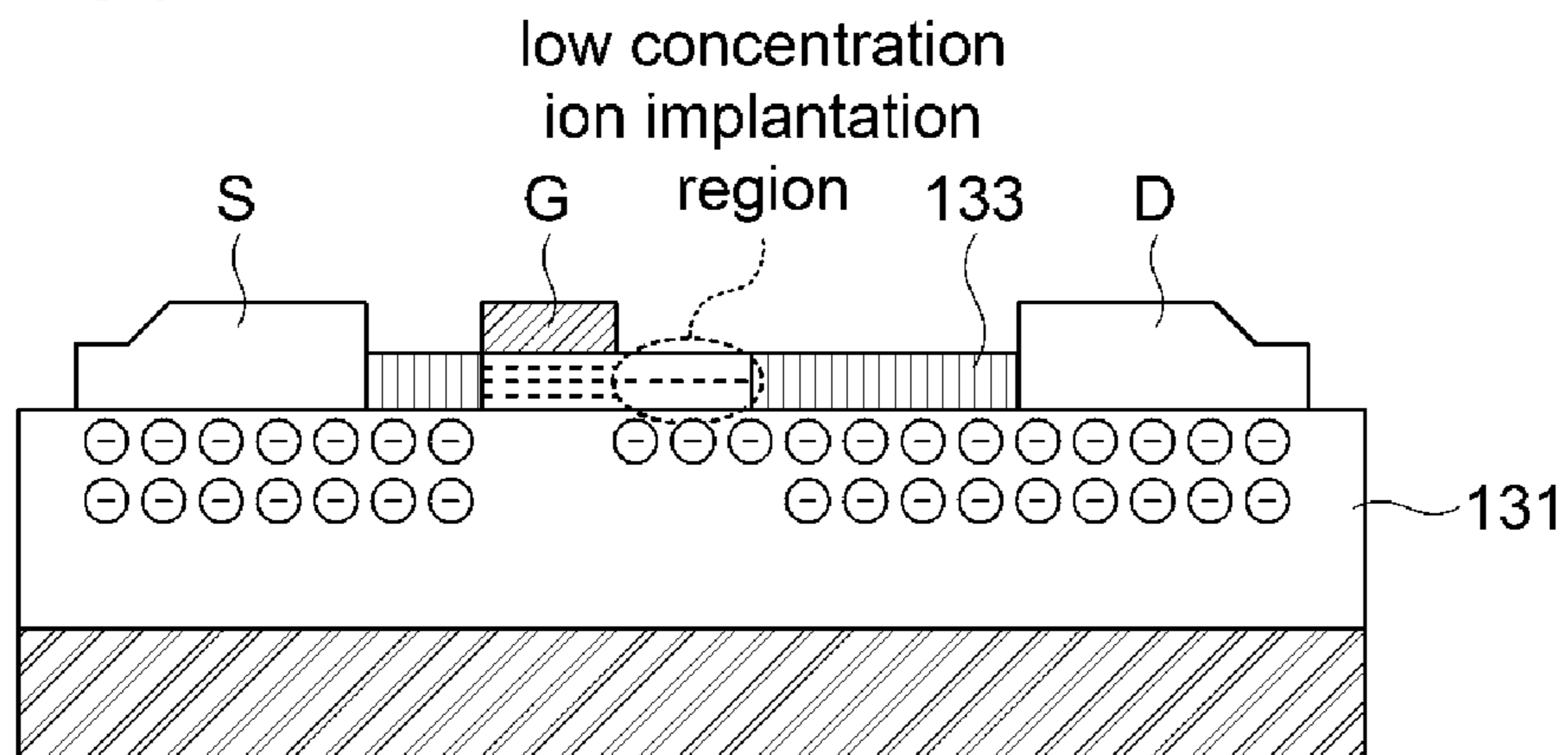
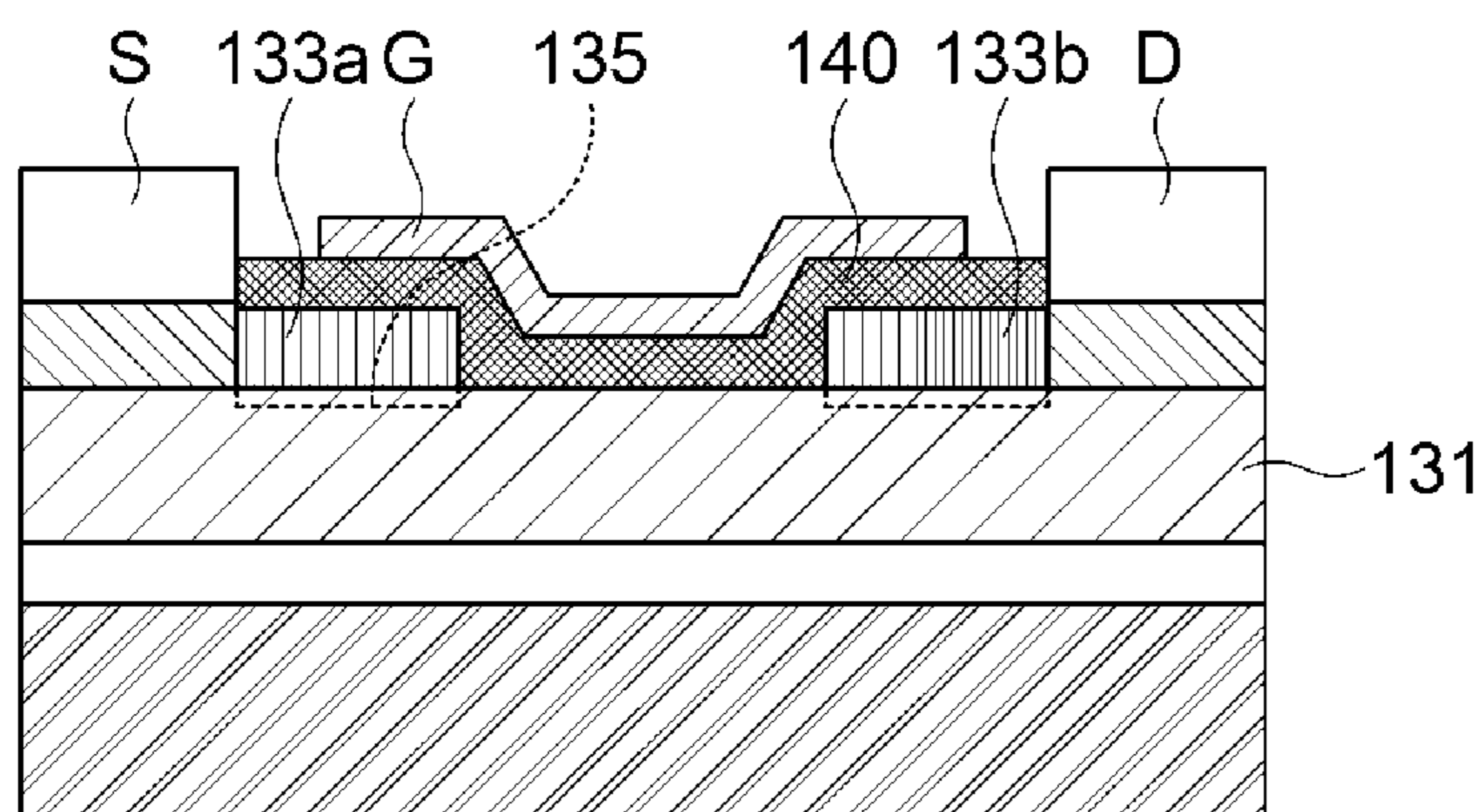


FIG. 8



- PRIOR ART -

FIG. 9



- PRIOR ART -

## 1

## SEMICONDUCTOR DEVICE

CROSS-REFERENCE TO RELATED  
APPLICATIONS

This application claims the benefit under 35 U.S.C. Section 119 of Korean Patent Application Serial No. 10-2011-0038611, filed Apr. 25, 2011, which is hereby incorporated by reference in its entirety into this application.

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The present invention relates to a nitride semiconductor device and a manufacturing method thereof, and more particularly, to a nitride semiconductor device capable of normally-off operation, and a manufacturing method thereof.

## 2. Description of the Related Art

There has been growing interest in reduction of power consumption due to green energy policy. To achieve this, improvement in power conversion efficiency is necessary. In the power conversion, efficiency of a power switching device has influence on the entire power conversion efficiency.

At present, most of power devices generally used are power MOSFETs or IGBTs using silicon. However, an increase in efficiency of the devices is limited due to material limitations of silicon. To overcome this, there have been patent applications which are to increase the conversion efficiency by manufacturing a transistor using a nitride semiconductor such as gallium nitride (GaN).

However, for example, a high electron mobility transistor (HEMT) structure using GaN becomes ON state in which current flows due to low resistance between a drain electrode and a source electrode when a gate voltage is 0V (normal state). Accordingly, this causes consumption of current and power, and there is a disadvantage that a negative voltage (for example, -5V) should be applied to a gate electrode so that the HEMT structure becomes OFF state (normally-on structure).

To overcome this disadvantage of the normally-on structure, patent applications as shown in FIGS. 8 and 9 were disclosed. FIGS. 8 and 9 show conventional HEMT structures.

FIG. 8 shows a drawing disclosed in publicized U.S. patent No. 2007-0295993. As shown in FIG. 8, in an AlGaN layer, concentration of a channel formed during growth of the AlGaN layer 133 is adjusted by implanting ions into a region under a gate G and a region adjacent to a gate electrode G between the gate G and a drain D. In FIG. 8, normally-off operation is implemented by controlling carrier concentration of a channel region 131 under the gate G by using ion implantation.

FIG. 9 is a drawing disclosed in U.S. Pat. No. 7,038,253. A 2DEG channel 135 is prevented from being formed under a gate electrode G by applying an insulation layer 140 on a channel layer 131 formed between first and second electron donor layers 133a and 133b and forming the gate electrode G on the insulation layer 140. In FIG. 9, normally-off operation is implemented by etching under a gate G through a recess process.

## SUMMARY OF THE INVENTION

There is a need for implementing a semiconductor device which operates normally-off and overcomes the problems of the normally-on structure as described above.

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The present invention has been invented in order to overcome the above-described problems and it is, therefore, an object of the present invention to provide a semiconductor device capable of normally-off (N-off) or enhancement-mode operation by forming a Schottky electrode in a source region of a semiconductor device, for example, an FET and forming a gate electrode in a portion of a source electrode region and in a portion of a nitride semiconductor region, and a manufacturing method thereof.

In accordance with one aspect of the present invention to achieve the object, there is provided a nitride semiconductor device including: a nitride semiconductor layer over a substrate wherein the nitride semiconductor has semiconductor layer over a substrate wherein the nitride semiconductor has a two-dimensional electron gas (2DEG) channel inside; a drain electrode in ohmic contact with the nitride semiconductor layer; a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode; a dielectric layer formed on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and a gate electrode disposed on the dielectric layer to be spaced apart from the drain electrode, wherein a portion of the gate electrode is formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween.

In accordance with another aspect of the present invention, the nitride semiconductor layer includes a first nitride layer over the substrate wherein the first nitride layer contains a gallium nitride (GaN)-based material; and a second nitride layer in heterojunction with and on the first nitride layer wherein the second nitride layer contains a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer.

Preferably, the first nitride layer contains GaN, and the second nitride layer contains one of aluminum gallium nitride (AlGaN), indium gallium nitride (InGaN), and indium aluminum gallium nitride (InAlGaN).

In accordance with another aspect of the present invention, the region of the dielectric layer disposed between the drain electrode and the source electrode includes a vertical or oblique step portion, wherein a portion in the direction of the drain electrode is formed higher than a portion in the direction of the source electrode.

In accordance with another aspect of the present invention, the gate electrode includes an extended field plate, wherein the field plate is spaced apart from the drain electrode and partially covers the portion of the dielectric layer in the direction of the drain electrode, which is formed higher.

In accordance with another aspect of the present invention, the nitride semiconductor device further includes a buffer layer between the substrate and the nitride semiconductor layer.

In accordance with another aspect of the present invention to achieve the object, there is provided a nitride semiconductor device including: a nitride semiconductor layer over a substrate wherein the nitride semiconductor has a 2DEG channel inside; a drain electrode in ohmic contact with the nitride semiconductor layer; a source electrode in Schottky contact with the nitride semiconductor layer while being spaced apart from the drain electrode; a dielectric layer formed on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and a gate electrode having a first region formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween and a sec-



ond region disposed on the dielectric layer between the drain electrode and the source electrode to be spaced apart from the drain electrode.

In accordance with another aspect of the present invention, the nitride semiconductor layer includes a first nitride layer over the substrate wherein the first nitride layer contains a GaN-based material; and a second nitride layer in heterojunction with and on the first nitride layer wherein the second nitride layer contains a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer.

In accordance with another aspect of the present invention, the first region and the second region of the gate electrode are separately formed, and the second region forms a floating gate.

In accordance with another aspect of the present invention, the nitride semiconductor device further includes a buffer layer between the substrate and the nitride semiconductor layer.

In the above-described aspects of the present invention, according to another feature, the substrate is a substrate using at least one of silicon (Si), silicon carbide (SiC), and sapphire ( $\text{Al}_2\text{O}_3$ ).

In the above-described aspect of the present invention, according to another feature, the dielectric layer contains at least one of SiN,  $\text{SiO}_2$ , and  $\text{Al}_2\text{O}_3$ .

In the above-described aspects of the present invention, according to another feature, the nitride semiconductor device is a power transistor device.

In accordance with still another aspect of the present invention to achieve the object, there is provided a method of manufacturing a nitride semiconductor device including the steps of: forming a nitride semiconductor layer over a substrate wherein the nitride semiconductor layer has a 2DEG channel inside; forming a drain electrode in ohmic contact with the nitride semiconductor layer and a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode; forming a dielectric layer on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and forming a gate electrode on the dielectric layer to be spaced apart from the drain electrode, wherein a portion of the gate electrode is formed on the dielectric layer over a drain-side edge portion of the source electrode.

In accordance with another aspect of the present method, the step of forming the nitride semiconductor layer includes the steps of: forming a first nitride layer containing a GaN-based material over the substrate through an epitaxial growth process; and forming a second nitride layer containing a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer through an epitaxial growth process by using the first nitride layer as a seed layer.

In accordance with another aspect of the present invention, in the step of forming the dielectric layer, after applying the dielectric layer on the nitride semiconductor layer between the drain electrode and the source electrode and on at least the portion of the source electrode, as the first step, at least the drain electrode is exposed and as the second step, in the region of the dielectric layer formed between the drain electrode and the source electrode, a portion in the direction of the drain electrode is vertically or obliquely stepped higher than a portion in the direction of the source electrode.

Furthermore, preferably, in the step of forming the gate electrode, the gate electrode is formed on the dielectric layer, and a field plate is extended from the gate electrode, wherein the field plate

partially covers the portion in the direction of the drain electrode which is stepped higher than the portion in the direction of the source electrode.

In accordance with still another aspect of the present invention to achieve the object, there is provided a method of manufacturing a nitride semiconductor device including the steps of: forming a nitride semiconductor layer over a substrate wherein the nitride semiconductor layer has a 2DEG channel inside; forming a drain electrode in ohmic contact with the nitride semiconductor layer and a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode; forming a dielectric layer on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and forming a gate electrode having a first region formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween and a second region disposed on the dielectric layer between the drain electrode and the source electrode to be spaced apart from the drain electrode.

In accordance with another aspect of the present method, in the step of forming the gate electrode, the first region and the second region of the gate electrode are separately formed, and the second region is formed as a floating gate on the dielectric layer between the drain electrode and the source electrode.

Further, in the above-described aspects of the present invention, according to another feature, in the step of forming the nitride semiconductor layer, before forming the nitride semiconductor layer over the substrate, the step of forming a buffer layer over the substrate is further included.

Although not explicitly described as preferable one aspect of the present invention, embodiments of the present invention in accordance with possible various combinations of the above-described technical features can be apparently implemented by those skilled in the art.

#### BRIEF DESCRIPTION OF THE DRAWINGS

These and/or other aspects and advantages of the present general inventive concept will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings of which:

FIG. 1 is a rough cross-sectional view of a nitride semiconductor device in accordance with an embodiment of the present invention;

FIGS. 2a to 2d are views roughly showing a method of manufacturing the nitride semiconductor device in accordance with FIG. 1;

FIG. 3 is a rough cross-sectional view of a nitride semiconductor device in accordance with another embodiment of the present invention;

FIG. 4 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention;

FIG. 5 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention;

FIGS. 6a to 6d show some processes of a method of manufacturing a nitride semiconductor device in accordance with still another embodiment of the present invention;

FIG. 7 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention; and

FIGS. 8 and 9 show conventional HEMT structures.

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DETAILED DESCRIPTION OF THE  
PREFERABLE EMBODIMENTS

Embodiments of the present invention to achieve the above objects will be described with reference to the accompanying drawings. In the following description, the same elements are represented by the same reference numerals, and additional description which is repeated or limits interpretation of the meaning of the invention may be omitted.

Before the specific description, in this specification, when an element is referred to as being “connected” or “coupled” to another element, it can be “directly” connected or coupled to the other element or connected or coupled to the other element with another element interposed therebetween, unless it is referred to as being “directly connected” or “directly coupled” to the other element.

Although the singular form is used in this specification, it should be noted that the singular form can be used as the concept representing the plural form unless being contradictory to the concept of the invention or clearly interpreted otherwise. It should be understood that the terms such as “having”, “including”, and “comprising” used herein do not preclude existence or addition of one or more other features or elements or combination thereof.

Further, the drawings referred to in this specification are ideal exemplary drawings for describing the embodiments of the present invention, and the size and thickness of films or layers or regions may be overdrawn for effective description of technical contents. Further, the shape of regions illustrated in the drawings is not intended to limit the scope of the invention, but is to illustrate the specific form of regions of devices.

Hereinafter, a semiconductor device and a manufacturing method thereof in accordance with embodiments of the present invention will be specifically described with reference to the accompanying drawings.

FIG. 1 is a rough cross-sectional view of a nitride semiconductor device in accordance with an embodiment of the present invention.

FIGS. 2a to 2d are views roughly showing a method of manufacturing the nitride semiconductor device in accordance with FIG. 1.

FIG. 3 is a rough cross-sectional view of a nitride semiconductor device in accordance with another embodiment of the present invention.

FIG. 4 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention.

FIG. 5 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention.

FIGS. 6a to 6d show some processes of a method of manufacturing a nitride semiconductor device in accordance with still another embodiment of the present invention.

FIG. 7 is a rough cross-sectional view of a nitride semiconductor device in accordance with still another embodiment of the present invention.

First, a nitride semiconductor device in accordance with an embodiment of the present invention will be specifically described with reference to FIGS. 1, 3, 4, 5, or 7.

Referring to FIGS. 1, 3, 4, 5, or 7, a nitride semiconductor device in accordance with an embodiment of the present invention includes a nitride semiconductor layer 30, a drain electrode 50, a source electrode 60, a dielectric layer 40, and a gate electrode 70 which are disposed over a substrate 10.

Referring to FIGS. 1, 4, 5, or 7, in this embodiment, the nitride semiconductor layer 30 is disposed over the substrate

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10. The substrate 10 may be a generally insulating substrate or a high resistance substrate substantially having insulation property.

In accordance with another embodiment of the present invention, in FIGS. 1, 3, 4, 5, or 7, the substrate 10 may be made of at least one of silicon (Si), silicon carbide (SiC), and sapphire ( $\text{Al}_2\text{O}_3$ ) or other well-known substrate materials.

The nitride semiconductor layer 30 may be directly formed on the substrate 10. Preferably, the nitride semiconductor layer 30 may be formed by epitaxially growing a single crystal thin film. As an epitaxial growth process for forming the nitride semiconductor layer 30, liquid phase epitaxy (LPE), chemical vapor deposition (CVD), molecular beam epitaxy (MBE), or metal-organic CVD (MOCVD) may be used.

Further, referring to FIG. 3, in accordance with another embodiment of the present invention, a buffer layer 20 may be formed between the substrate 10 and the nitride semiconductor layer 30, and the nitride semiconductor layer 30 may be formed on the buffer layer 20. The buffer layer 20 is provided so as to solve problems due to a lattice mismatch between the substrate 10 and the nitride semiconductor layer 30. The buffer layer 20 may be formed in one layer as well as a plurality of layers containing gallium nitride (GaN), aluminum gallium nitride (AlGaN), aluminum nitride (AlN), indium gallium nitride (InGaN) or indium aluminum gallium nitride (InAlGaN). Further, the buffer layer 20 may be made of group III-V compound semiconductors other than GaN. For example, when the substrate 10 is a sapphire substrate 10, growth of the buffer layer 20 is important to avoid a mismatch due to differences in lattice constant and coefficient of thermal expansion between the substrate 10 and the nitride semiconductor layer 30 containing GaN.

Referring to FIGS. 1, 3, 4, 5, or 7, a two-dimensional electron gas (2DEG) channel 35 is formed in the nitride semiconductor layer 30. When a bias voltage is applied to the gate electrode 70 of the nitride semiconductor device, electrons move through the 2DEG channel 35 in the nitride semiconductor layer 30 so that current flows between the drain electrode 50 and the source electrode 60. The nitride semiconductor layer 30 is made of nitride such as GaN, AlGaN, InGaN, or InAlGaN.

In accordance with an embodiment of the present invention, the nitride semiconductor layer 30 is a heterojunction GaN-based semiconductor layer 30, and the 2DEG channel 35 is formed in the vicinity of a heterojunction interface by an energy band gap difference. The less the difference in lattice constant between heterojunctions of the heterojunction GaN-based semiconductor layer 30 is, the less the differences in band gap and polarity are. Due to this, the formation of the 2DEG channel 35 is suppressed. Free electrons move from a material with a wide band gap to a material with a small band gap by discontinuity of the energy band gap during heterojunction. These electrons are accumulated on the heterojunction interface to form the 2DEG channel 35 so that current flows between the drain electrode 50 and the source electrode 60.

Referring to FIGS. 1, 3, 4, 5, or 7, the nitride semiconductor layer 30 includes a first nitride layer 31 and a second nitride layer 33. The first nitride layer 31 is disposed over the substrate 10 and contains a GaN-based material. The second nitride layer 33 is in heterojunction with and on the first nitride layer 31 and contains a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer 31. At this time, the second nitride layer 33 plays a role of supplying electrons to the 2DEG channel 35 formed in the first nitride layer 31. For example, it is preferred that the

second nitride layer 33, which donates electrons, is formed with a thickness smaller than that of the first nitride layer 31.

Preferably, in accordance with another embodiment of the present invention, the first nitride layer 31 contains GaN, and the second nitride layer 33 contains one of AlGaN, InGaN, and InAlGaN. Preferably, in accordance with an embodiment of the present invention, the first nitride layer 31 contains GaN, and the second nitride layer 33 contains AlGaN.

Continuously, configurations of embodiments of the present invention will be further described with reference to FIGS. 1, 3, 4, 5, or 7.

Referring to FIGS. 1, 3, 4, 5, or 7, the drain electrode 50 and the source electrode 60 of the nitride semiconductor device in accordance with this embodiment are formed on the nitride semiconductor layer 30. The drain electrode 50 is in ohmic contact 50a with the nitride semiconductor layer 30.

The source electrode 60 is disposed to be spaced apart from the drain electrode 50 and in Schottky contact 60a with the nitride semiconductor layer 30. Along the Schottky source electrode 60, when driven in a reverse direction, a current flow by 2DEG can be stably interrupted by a depletion region formed by a Schottky contact region 60a of the source electrode 60. Accordingly, it is possible to interrupt a reverse current flow and implement a normally-off state. More specifically, when a reverse bias voltage is applied, the depletion region formed by the Schottky contact region 60a of the source electrode 60 is expanded to the region of the 2DEG channel 35 so that the 2DEG channel 35 is blocked and a reverse breakdown voltage is increased. Especially, when the reverse bias voltage is applied, the depletion region is greatly expanded in the Schottky contact region 60a adjacent to a drain-side corner of the source electrode 60. Meanwhile, when a forward bias voltage is applied, the depletion region formed by the Schottky contact region 60a of the source electrode 60 is reduced so that current flows between the drain electrode 50 and the source electrode 60 through the 2DEG channel 35.

Continuously, referring to FIGS. 1, 3, 4, 5, or 7, the dielectric layer 40 of the nitride semiconductor device in accordance with an embodiment of the present invention is formed on the nitride semiconductor layer 30 between the drain electrode 50 and the source electrode 60 and on at least a portion of the source electrode 60.

Another embodiment of the present invention will be described with reference to FIG. 4. Referring to FIG. 4, the region of the dielectric layer 40 disposed between the drain electrode 50 and the source electrode 60 has a vertical or oblique (not shown) step portion. Along the vertical or oblique step portion, a portion of the dielectric layer 40 in the direction of the drain electrode 50 is formed higher than a portion of the dielectric layer 40 in the direction of the source electrode 60.

Preferably, in accordance with another embodiment of the present invention, in FIGS. 1, 3, 4, 5, or 7, the dielectric layer 40 may be an oxide layer, and in accordance with an embodiment, the dielectric layer 40 may contain at least one of SiN, SiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub>.

Continuously, referring to FIGS. 1, 3, 4, 5, or 7, the gate electrode 70 of the nitride semiconductor device in accordance with this embodiment is disposed on the dielectric layer 40 to be spaced apart from the drain electrode 50. Furthermore, referring to FIGS. 1, 3, 4, 5, or 7, a portion of the gate electrode 70 is formed over a drain-side edge portion of the source electrode 60 with the dielectric layer 40 interposed therebetween. Preferably, the gate electrode 70 is in Schottky contact 70a with the dielectric layer 40. When a forward bias voltage is applied to the gate electrode 70, the depletion

region formed in the Schottky contact region 60a adjacent to the drain-side corner of the source electrode 60 is reduced so that current flows between the drain electrode 50 and the source electrode 60 through the 2DEG channel 35.

Referring to FIGS. 1, 3, 4, or 5, the gate structure is formed over the edge portion of the source electrode 60 and on the dielectric layer 40 between the drain electrode 50 and the source electrode 60 to distribute an electric field. Accordingly, the gate structure itself performs a role of a field plate for increasing a withstand voltage.

Another embodiment of the present invention will be described with reference to FIG. 5. Referring to FIG. 5, the gate electrode 70 of the nitride semiconductor device includes an extended field plate 75. The field plate 75 extended from the gate electrode 70 is spaced apart from the drain electrode 50. Further, the extended field plate 75, as shown in FIG. 4, is formed to partially cover the portion of the dielectric layer 40 in the direction of the drain electrode 50, which is formed high along the vertical or oblique (not shown) step portion of the region of the dielectric layer 40 disposed between the drain electrode 50 and the source electrode 60. The extended field plate 75 provides an effect of distributing an electric field concentrated in a drain-side corner portion of the Schottky-contacted gate electrode 70.

Further, another embodiment of the present invention will be described with reference to FIGS. 1 or/and 7.

Referring to FIGS. 1 or/and 7, a nitride semiconductor device in accordance with an embodiment of the present invention includes a nitride semiconductor layer 30, a drain electrode 50, a source electrode 60, a dielectric layer 40, and a gate electrode 70 which are disposed over a substrate 10. The nitride semiconductor layer 30, the drain electrode 50, the source electrode 60, and the dielectric layer 40 will refer to the above description.

In this embodiment, the gate electrode 70 includes a first region 71 and 71' and a second region 73 and 73'. The first region 71 and 71' is formed over a drain-side edge portion of the source electrode 60 with the dielectric layer 40 interposed therebetween. The second region 73 and 73' is disposed on the dielectric layer 40 between the drain electrode 50 and the source electrode 60 to be spaced apart from the drain electrode 50. The first region and the second region may be integrally formed as shown in FIG. 1 or may be separately formed as shown in FIG. 7.

When describing another embodiment of the present invention with reference to FIG. 7, the first region 71' and the second region 73' of the gate electrode 70 are separately formed. At this time, the second region 73' forms a floating gate. Since the second region 73' performs a role of a floating gate, an electric field is distributed by the second region 73'. Preferably, the second region 73' is disposed close to the source electrode 60.

Although not shown in FIG. 7, in accordance with another embodiment of the present invention, as shown in FIG. 3, a buffer layer 20 may be formed between the substrate 10 and the nitride semiconductor layer 30, and the nitride semiconductor layer 30 may be formed on the buffer layer 20.

In accordance with an embodiment of the present invention according to FIGS. 1, 3, 4, 5, or 7, when a voltage of 0(V) is applied to the gate electrode 70, a current flow between the drain electrode 50 and the source electrode 60 through a 2DEG channel 35 is interrupted by a Schottky barrier in the region of the source electrode 60. And when a voltage higher than a threshold voltage is applied to the gate electrode 70, carrier (electron) concentration is increased in the drain-side edge region of the source electrode 60 so that current flows by a tunneling phenomenon. At this time, the threshold voltage

of the gate is determined by a thickness of the dielectric layer **40**. Accordingly, the nitride semiconductor device in accordance with the present invention is easily manufactured and has low leakage current and high withstand voltage characteristics, compared to a conventional normally-off (N-off) HEMT structure.

The nitride semiconductor device in accordance with the above-described embodiments is a power transistor device. The power transistor device in accordance with an embodiment of the present invention has a horizontal HEMT structure.

Next, a method of manufacturing a nitride semiconductor device in accordance with another aspect of the present invention will be described with reference to the drawings. The nitride semiconductor device described in the above embodiments and FIGS. **1**, **3**, **4**, **5**, and **7** as well as FIGS. **2a** to **2d** and **6a** to **6d** will be referred to in describing the method of manufacturing a nitride semiconductor device in accordance with the present invention.

FIGS. **2a** to **2d** show a method of manufacturing a nitride semiconductor device in accordance with one aspect of the present invention.

Preferably, in accordance with an embodiment, a device manufactured by a method of manufacturing a nitride semiconductor device of the present invention is a power transistor.

First, referring to FIG. **2a**, a nitride semiconductor layer **30**, which has a 2DEG channel **35** inside, is formed over a substrate **10**. Preferably, the substrate **10** may be made of at least one of Si, SiC, and Al<sub>2</sub>O<sub>3</sub>. The nitride semiconductor layer **30** is made of nitride such as GaN, AlGa<sub>x</sub>N<sub>1-x</sub>, InGa<sub>x</sub>N<sub>1-x</sub>, or InAlGa<sub>x</sub>N<sub>1-x</sub>.

Preferably, the nitride semiconductor layer **30** may be formed by epitaxially growing a nitride single crystal thin film. Preferably, the nitride semiconductor layer **30** is selectively grown during the epitaxial growth so as not to be overgrown. If the nitride semiconductor layer **30** is overgrown, it may be additionally planarized by an etch-back process or a chemical mechanical polishing (CMP) process.

In accordance with another embodiment of a method of manufacturing a nitride semiconductor device of the present invention, a first nitride layer **31** and a second nitride layer **33** shown in FIG. **2a** are formed by an epitaxial growth process. First, the first nitride layer **31** is formed by epitaxially growing a GaN-based single crystal thin film on the substrate **10**. Preferably, in accordance with another embodiment of the present invention, the first nitride layer **31** is formed by epitaxially growing GaN. Next, the second nitride layer **33** is formed by epitaxially growing a nitride layer containing a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer **31** by using the first nitride layer **31** as a seed layer. Preferably, in accordance with another embodiment of the present invention, the second nitride layer **33** is formed by epitaxially growing GaN-based single crystal containing one of AlGa<sub>x</sub>N<sub>1-x</sub>, InGa<sub>x</sub>N<sub>1-x</sub>, and InAlGa<sub>x</sub>N<sub>1-x</sub>. Preferably, the second nitride layer **33** is formed by epitaxially growing AlGa<sub>x</sub>N<sub>1-x</sub>. For example, it is preferred that the second nitride layer **33**, which donates electrons, is formed with a thickness smaller than that of the first nitride layer **31**.

The first and second nitride layers **31** and **33** may be formed by an epitaxial growth process such as liquid phase epitaxy (LPE), chemical vapor deposition (CVD), molecular beam epitaxy (MBE), or metal-organic CVD (MOCVD).

Next, referring to FIG. **2b**, a drain electrode **50** and a source electrode **60** are formed on the nitride semiconductor layer **30**. In FIG. **2b**, the drain electrode **50** is formed to be in ohmic contact **50a** with the nitride semiconductor layer **30**. Heat-

treatment can be performed to complete ohmic contact. The drain metal electrode **50** is formed on the nitride semiconductor layer **30** by using at least one metal of gold (Au), nickel (Ni), platinum (Pt), titanium (Ti), aluminum (Al), palladium (Pd), iridium (Ir), rhodium (Rh), cobalt (Co), tungsten (W), molybdenum (Mo), tantalum (Ta), copper (Cu), and zinc (Zn), metal silicide, and alloys thereof. The drain electrode **50** may be formed in a multilayer structure.

The source electrode **60** is formed to be in Schottky contact **60a** with the nitride semiconductor layer **30** while being spaced apart from the drain electrode **50**. The Schottky-contacted source metal electrode **60** is formed by using a material, which can be in Schottky contact with the nitride semiconductor layer **30**, for example, at least one metal of Al, Mo, Au, Ni, Pt, Ti, Pd, Ir, Rh, Co, W, Ta, Cu, and Zn, metal silicide, and alloys thereof. The source electrode **60** may be formed in a multilayer structure. It is possible to interrupt reverse current between the drain electrode **50** and the source electrode **60** through the 2DEG channel **35** by using the Schottky contact **60a** having semiconductor contact with metal in the source electrode **60**.

When describing a process of forming the drain electrode **50** and the source electrode **60** in accordance with an embodiment of the present invention, a metal layer for forming an electrode is formed by an electron beam evaporator on the nitride semiconductor layer **30**, which is epitaxially grown on the substrate **10**, and a photoresist pattern is formed on the metal layer. The metal electrodes **50** and **60** are formed by etching the metal layer using the photoresist pattern as an etching mask and removing the photoresist pattern.

Referring to FIG. **2c**, in an embodiment of the present invention, after forming the drain electrode **50** and the source electrode **60**, a dielectric layer **40** is formed on the nitride semiconductor layer **30** between the drain electrode **50** and the source electrode **60**. At this time, the dielectric layer **40** is formed on at least a portion of the source electrode **60**, preferably, on a portion of the source electrode **60** in the direction of the drain electrode **50**. Preferably, the dielectric layer **40** may be an oxide layer or may include at least one of SiN, SiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub> in accordance with an embodiment.

A process of forming the dielectric layer **40** in accordance with another embodiment of the present invention will be described with reference to FIGS. **6a** to **6c**. Referring to FIG. **6a**, the dielectric layer **40** is applied to or coated on the nitride semiconductor layer **30**, the drain electrode **50**, and the source electrode **60**. Preferably, the dielectric layer **40** is applied to or coated on the nitride semiconductor layer **30** between the drain electrode **50** and the source electrode **60** and on at least a portion of the source electrode **60**.

Next, referring to FIG. **6b**, after applying the dielectric layer **40**, as the first step, at least the drain electrode **50** is exposed. For example, the drain electrode **50** is exposed by etching or polishing.

And, referring to FIG. **6c**, as the second step, a vertical or oblique (not shown) step portion is formed in the region of the dielectric layer **40** between the drain electrode **50** and the source electrode **60** by forming a portion in the direction of the drain electrode **50** higher than a portion in the direction of the source electrode **60**. The step portion is formed by additionally depositing the dielectric layer **40** in the portion in the direction of the drain electrode **50** or partially etching the portion of the dielectric layer **40** in the direction of the source electrode **60**.

Referring to FIG. **2d**, in an embodiment of the present invention, after forming the dielectric layer **40** in accordance with FIG. **2c**, a gate electrode **70** is formed on the dielectric layer **40** to be spaced apart from the drain electrode **50**. At this

time, referring to FIG. 2*d*, a portion of the gate electrode 70 is formed on the dielectric layer 40 over a drain-side edge portion of the source electrode 60. The gate electrode 70 may be made of at least one metal of Al, Mo, Au, Ni, Pt, Ti, Pd, Ir, Rh, Co, W, Ta, Cu, and Zn, metal silicide, and alloys thereof. The gate electrode 70 may use a metal different from those of the drain electrode 50 or/and the source electrode 60 and may be formed in a multilayer structure. Preferably, the gate electrode 70 is in Schottky contact 70*a* with the dielectric layer 40.

When describing a process of forming the gate electrode 70 in accordance with an embodiment of the present invention, a metal layer for forming an electrode is formed on the dielectric layer 40 by an electron beam evaporator, and a photoresist pattern is formed on the metal layer so that a portion of the gate electrode 70 is formed on the dielectric layer 40 on the drain-side edge portion of the source electrode 60. And the metal layer is etched by using the photoresist pattern as an etching mask. The metal electrode is formed by removing the photoresist pattern after etching.

Further, in the method of manufacturing a nitride semiconductor device in accordance with another embodiment of the present invention, a process of forming the gate electrode 70 on the dielectric layer 40 will be described with reference to FIG. 6*d*. Referring to FIG. 6*d*, a field plate 75 extends from the gate electrode 70 to be spaced apart from the drain electrode 50. At this time, the field plate 75 is formed to partially cover the portion of the dielectric layer 40 in the direction of the drain electrode 50, which is stepped higher than the portion of the dielectric layer 40 in the direction of the source electrode 60. For example, the field plate 75 may be integrally formed with the gate electrode 70 during the formation of the gate electrode 70 or may be formed by forming the same or different metal layer from the gate electrode 70 after forming the gate electrode 70, forming a photoresist pattern, and performing an etching process. The field plate 75 provides an effect of distributing an electric field concentrated in a drain-side corner portion of the Schottky-contacted gate electrode 70.

Further, when describing another embodiment of the present invention with reference to FIGS. 2*d* and 7, the gate electrode 70 includes a first region 71 and 71' and a second region 73 and 73'. The first region 71 and 71' of the gate electrode 70 is formed over the drain-side edge portion of the source electrode 60 with the dielectric layer 40 interposed therebetween, and the second region 73 and 73' of the gate electrode 70 is formed on the dielectric layer 40 between the drain electrode 50 and the source electrode 60 to be spaced apart from the drain electrode 50. The first region and the second region may be integrally formed as shown in FIG. 2*d* or may be separately formed as shown in FIG. 7.

When describing another embodiment of the present invention with reference to FIG. 7, in the step of forming the gate electrode 70, the first region 71' and the second region 73' of the gate electrode 70 are separately formed, and the second region 73' is formed as a floating gate on the dielectric layer 40 between the drain electrode 50 and the source electrode 60.

In accordance with another embodiment of a method of manufacturing a nitride semiconductor device of the present invention, referring to FIG. 3, before forming the nitride semiconductor layer 30 over the substrate 10 shown in FIG. 2*a*, the step of forming a buffer layer 20 over the substrate 10 is further included. The buffer layer 20 is provided to solve problems due to a lattice mismatch between the substrate 10 and the nitride semiconductor layer 30. The buffer layer 20 may be formed in one layer or a plurality of layers containing GaN, AlGaN, AlN, InGaN, or InAlGaN.

In accordance with one aspect of the present invention, it is possible to obtain a semiconductor device capable of normally-off (N-off) or enhancement-mode operation by forming a Schottky electrode in a source region of a semiconductor device, for example, an FET and forming a gate electrode in a portion of a source electrode region and in a portion of a nitride semiconductor region.

A semiconductor device and a manufacturing method thereof in accordance with an embodiment of the present invention can perform high withstand voltage operation compared to a conventional GaN normally-off device and facilitate manufacture of the device by simple manufacturing processes. That is, since difficult processes such as ion implantation and etching of an AlGaN layer with a thickness of 200 to 300 Å of the conventional normally-off HEMT are not required, the manufacture of the device is facilitated.

Further, in accordance with an embodiment of the present invention, it is possible to achieve low leakage current and high withstand voltage compared to the conventional normally-off HEMT by a structure in which leakage current is prevented by a Schottky barrier of a source electrode.

Furthermore, in accordance with an embodiment of the present invention, a gate structure can perform a role of a field plate for increasing a withstand voltage at the same time by being formed on an edge portion of the source electrode and on a dielectric layer between a drain electrode and the source electrode to distribute an electric field.

Further, it is possible to increase transconductance by reducing a distance between the source electrode and the gate electrode.

It will be apparent that various effects, which are not directly stated in accordance with various embodiments of the present invention, can be derived from various configurations in accordance with embodiments of the present invention by those skilled in the art.

The above-described embodiments and the accompanying drawings are provided as examples to help understanding of those skilled in the art, not limiting the scope of the present invention. Therefore, the various embodiments of the present invention may be embodied in different forms in a range without departing from the essential concept of the present invention, and the scope of the present invention should be interpreted from the invention defined in the claims. It is to be understood that the present invention includes various modifications, substitutions, and equivalents by those skilled in the art.

What is claimed is:

1. A nitride semiconductor device comprising:

1. A nitride semiconductor device comprising:
  - a nitride semiconductor layer over a substrate wherein the nitride semiconductor has a two-dimensional electron gas (2DEG) channel inside;
  - a drain electrode in ohmic contact with the nitride semiconductor layer;
  - a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode;
  - a dielectric layer formed on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and
  - a gate electrode disposed on the dielectric layer to be spaced apart from the drain electrode, wherein a portion of the gate electrode is formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween.

2. The nitride semiconductor device according to claim 1, wherein the nitride semiconductor layer comprises:

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a first nitride layer over the substrate wherein the first nitride layer contains a gallium nitride (GaN)-based material; and

a second nitride layer in heterojunction with and on the first nitride layer wherein the second nitride layer contains a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer.

3. The nitride semiconductor device according to claim 2, wherein the first nitride layer contains GaN, and the second nitride layer contains one of aluminum gallium nitride (Al-GaN), indium gallium nitride (InGaN), and indium aluminum gallium nitride (InAlGaN).

4. The nitride semiconductor device according to claim 1, wherein the region of the dielectric layer disposed between the drain electrode and the source electrode comprises a vertical or oblique step portion, wherein a portion in the direction of the drain electrode is formed higher than a portion in the direction of the source electrode.

5. The nitride semiconductor device according to claim 4, wherein the gate electrode comprises an extended field plate, wherein the field plate is spaced apart from the drain electrode and partially covers the portion of the dielectric layer in the direction of the drain electrode, which is formed higher.

6. The nitride semiconductor device according to claim 1, further comprising:

a buffer layer formed between the substrate and the nitride semiconductor layer.

7. The nitride semiconductor device according to claim 1, wherein the substrate is made of at least one of silicon (Si), silicon carbide (SiC), and sapphire ( $Al_2O_3$ ).

8. The nitride semiconductor device according to claim 1, wherein the dielectric layer contains at least one of SiN,  $SiO_2$ , and  $Al_2O_3$ .

9. The nitride semiconductor device according to claim 1, wherein the nitride semiconductor device is a power transistor device.

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10. A nitride semiconductor device comprising:

a nitride semiconductor layer over a substrate wherein the nitride semiconductor has a 2DEG channel inside;

a drain electrode in ohmic contact with the nitride semiconductor layer;

a source electrode in Schottky contact with the nitride semiconductor layer wherein the source electrode is spaced apart from the drain electrode;

a dielectric layer formed on the nitride semiconductor layer between the drain electrode and the source electrode and on at least a portion of the source electrode; and

a gate electrode having a first region formed over a drain-side edge portion of the source electrode with the dielectric layer interposed therebetween and a second region disposed on the dielectric layer between the drain electrode and the source electrode to be spaced apart from the drain electrode.

11. The nitride semiconductor device according to claim 10, wherein the nitride semiconductor layer comprises:

a first nitride layer over the substrate wherein the first nitride layer contains a GaN-based material; and

a second nitride layer in heterojunction with and on the first nitride layer wherein the second nitride layer contains a heterogeneous GaN-based material with a wider energy band gap than the first nitride layer.

12. The nitride semiconductor device according to claim 10, wherein the first region and the second region of the gate electrode are separately formed, and the second region forms a floating gate.

13. The nitride semiconductor device according to claim 10, further comprising:

a buffer layer formed between the substrate and the nitride semiconductor layer.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 8,896,026 B2  
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DATED : November 25, 2014  
INVENTOR(S) : Woo Chul Jeon et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page, Item (54) and in the Specification, Column 1, Line 1, in the Title, delete "SEMICONDUCTOR" and insert -- SEMICONDUCTOR --, therefor.

Signed and Sealed this  
Fifth Day of May, 2015



Michelle K. Lee  
*Director of the United States Patent and Trademark Office*